A-LEVEL MATHS (EDEXCEL 9MA0) · MECHANICS YEAR 1 · CHAPTER 8: MODELLING IN MECHANICS · A* EXAM PRACTICE

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Modelling in mechanics: A* questions

76 marks

Date

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X A* exam questions

A to A*

Extended Edexcel-style questions. Show every step. The hints are at the end of the sheet. Use one at a time.

X1 In this question $\mathbf{i}$ is east, $\mathbf{j}$ is north and distances are in km. Two ships A and B move with constant velocities. At noon A is at $(-4\mathbf{i} + 18\mathbf{j})$ and B is at $(6\mathbf{i} - 2\mathbf{j})$. The velocity of A is $(8\mathbf{i} - 2\mathbf{j})\ \text{km h}^{-1}$ and the velocity of B is $(2\mathbf{i} + 6\mathbf{j})\ \text{km h}^{-1}$. At time t hours after noon the distance between the ships is d km.

(a) Show that $\overrightarrow{AB} = (10 - 6t)\mathbf{i} + (8t - 20)\mathbf{j}$. [3 marks]

(b) Show that $d^2 = 100t^2 - 440t + 500$. [3 marks]

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(c) By completing the square, find the least distance between the ships and the time when it happens. [3 marks]

Answer .....

(d) A radio link works while the ships are within 10 km of each other. Find, to the nearest minute, how long the link works. [3 marks]

Answer .....

(e) Find the bearing of B from A when the ships are closest. [2 marks]

Answer .....

Total for X1: 14 marks

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X2 A ship S is in difficulty. At 1 pm it is at the point $(20\mathbf{i} + 5\mathbf{j})$ km relative to a harbour O, where $\mathbf{i}$ is east and $\mathbf{j}$ is north, and it drifts with constant velocity $(-4\mathbf{i} + 3\mathbf{j})\ \mathrm{km\ h^{-1}}$. At 1 pm a lifeboat leaves O and travels in a straight line at a constant speed of $10\ \mathrm{km\ h^{-1}}$, so that it meets the ship. Find the time when the lifeboat meets the ship, and the bearing on which the lifeboat travels. [11 marks]

Answer .....

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X3 In this question $\mathbf{i}$ is east and $\mathbf{j}$ is north, and distances are in km. A ship leaves a port O and sails at $15\ \text{km h}^{-1}$ on a bearing of 060° for 2 hours, to the point A. It then sails in a straight line at $12\ \text{km h}^{-1}$ to a point B, which is 40 km due east of O.

(a) Show that $\overrightarrow{AB} = (40 - 15\sqrt{3})\mathbf{i} - 15\mathbf{j}$. [2 marks]

(b) Show that $AB^2 = 2500 - 1200\sqrt{3}$, and find the distance AB and the bearing of B from A. [4 marks]

Answer .....

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(c) Find the total time for the journey from O to B. [2 marks]

Answer .....

(d) The ship is modelled as a particle moving with constant velocity on each part of the journey. Give one way in which this model may not match the real journey, and its effect on the answer to (c). [2 marks]

Total for X3: 10 marks

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X4 A basketball is thrown towards a hoop. Its height h m above the floor when it has travelled a horizontal distance x m is modelled by $h = a + bx - cx^2$, where a, b and c are constants. The ball is released at a height of 2.1 m, and it passes through the points $(2, 3.3)$ and $(4, 3.7)$.

(a) Find a, b and c. [4 marks]

Answer .....

(b) By completing the square, find the greatest height of the ball and the value of x where it happens. [3 marks]

Answer .....

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(c) The centre of the hoop is 3.05 m above the floor, and the ball passes through it on the way down. Find the horizontal distance from the point of release to the hoop. [3 marks]

Answer .....

(d) When $x = 6$ the ball was measured at a height of 3.2 m. Comment on this, and suggest one refinement to the model. [2 marks]

Total for X4: 12 marks

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X5 Two particles P and Q move in a horizontal plane with constant velocities. At time t seconds their position vectors, in metres relative to a fixed point O, are $\mathbf{r}_P = (3\mathbf{i} + 2\mathbf{j}) + t(\mathbf{i} + 3\mathbf{j})$ and $\mathbf{r}_Q = (-\mathbf{i} + 12\mathbf{j}) + t(4\mathbf{i} - \mathbf{j})$, where $\mathbf{i}$ is east and $\mathbf{j}$ is north. Find the time when Q is due east of P. Find also the time when Q is south-east of P, and the distance PQ at that time. [9 marks]

Answer .....

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X6 A van drives along a straight road from A to B at a constant speed of $u\ \text{km h}^{-1}$, then straight back from B to A at a constant speed of $v\ \text{km h}^{-1}$.

(a) Show that the average speed for the whole journey is $\dfrac{2uv}{u+v}\ \text{km h}^{-1}$. [3 marks]

(b) Prove that this average speed is less than $\dfrac{u+v}{2}$ unless $u = v$. [3 marks]

(c) Explain why the average velocity for the whole journey is zero. [2 marks]

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(d) Given that $u = 12$ and the average speed is $15\ \text{km h}^{-1}$, find v. [2 marks]

Answer .....

Total for X6: 10 marks

X7 A boat starts at a fixed point O. It moves with velocity $(6\mathbf{i} + 8\mathbf{j})\ \text{km h}^{-1}$ for 2 hours, then with velocity $(k\mathbf{i} - 4\mathbf{j})\ \text{km h}^{-1}$ for 3 hours, where k is a constant and $\mathbf{i}$ is east, $\mathbf{j}$ is north. The magnitude of its average velocity over the 5 hours is $4\ \text{km h}^{-1}$, and its speed on the second part is less than $10\ \text{km h}^{-1}$.

(a) Show that $(12 + 3k)^2 = 384$. [3 marks]

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(b) Find the exact value of k, explaining why one solution is rejected. [4 marks]

Answer .....

(c) Find the bearing of the boat from O at the end of the 5 hours. [3 marks]

Answer .....

Total for X7: 10 marks

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F How did it go?

Colour one circle on each line.

	Not yet	Nearly	Yes
I can find when two objects moving with constant velocity are closest, by completing the square.	○	○	○
I can find the course an object must take to meet another, from a quadratic in time.	○	○	○
I can fit a model to data, use it, and say how well it matches a measurement.	○	○	○
I can use a condition on a magnitude or a direction to find an unknown, and reject a value that does not fit the context.	○	○	○

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Hints

Use one hint at a time. Cover the ones below it with a sheet of paper.

X1	**Hint 1**	Write each position as start $+ t\times$ velocity. $\overrightarrow{AB}$ is "where B is" minus "where A is".
	Hint 2	Complete the square on $100t^2 - 440t + 500$: the least value of d^2 is the constant that is left.
	Hint 3	Within 10 km means $d^2 < 100$. Solve the quadratic inequality; the time is the gap between the two critical values.
X2	**Hint 1**	The lifeboat goes from O to the meeting point in a straight line, so the distance from O to the ship's position at time t equals $10t$.
	Hint 2	Square both sides to get a quadratic in t. A negative time is before 1 pm.
	Hint 3	The lifeboat's velocity is the meeting point's position vector divided by the time taken.
X3	**Hint 1**	$\overrightarrow{OA}$ has length 15×2 on a bearing of $060°$: use $\sin 60° = \frac{\sqrt{3}}{2}$ and $\cos 60° = \frac{1}{2}$.
	Hint 2	$\overrightarrow{AB} = \overrightarrow{OB} - \overrightarrow{OA}$, with $\overrightarrow{OB} = 40\mathbf{i}$.
	Hint 3	Sketch $\overrightarrow{AB}$: it points east and south. The bearing is $180°$ minus the angle it makes with south.
X4	**Hint 1**	At release $x = 0$, so a is the release height. Put each point into the model to get two equations.
	Hint 2	$h = 2.1 - 0.1(x^2 - 8x)$. Complete the square inside the bracket.
	Hint 3	A height on the way down is at the larger value of x that gives that height.
X5	**Hint 1**	Everything is about where Q is seen from P: work with $\overrightarrow{PQ} = \mathbf{r}_Q - \mathbf{r}_P$.
	Hint 2	"Due east" means the $\mathbf{j}$ part is zero and the $\mathbf{i}$ part is positive.
	Hint 3	"South-east" means the vector points equally east and south: the $\mathbf{i}$ part is positive and the $\mathbf{j}$ part is its negative.

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X6

Hint 1 Call the distance AB something, say s. Average speed is total distance over total time.

Hint 2 Subtract one expression from the other and write the difference as one fraction. Look at the numerator.

Hint 3 Average velocity uses the displacement, not the distance.

X7

Hint 1 Average velocity is total displacement divided by 5. Find the total displacement first.

Hint 2 A square root has two signs. Each sign gives a value of k.

Hint 3 The speed on the second part is $\sqrt{k^2 + 4^2}$. Only one value of k makes this less than 10.

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